PATENT SPECIFICATION

(11) 1293531

DRAWINGS ATTACHED

(21) Application No. 34726/68 (22) Filed 20 July 1968

(23) Complete Specification filed 20 Oct. 1969

(45) Complete Specification published 18 Oct. 1972

(51) International Classification B23K 19/00

(52) Index at acceptance

B3R 10 14 15

(72) Inventor JOHN GILBERT SEARLE

(54) IMPROVEMENTS RELATING TO METHODS OF AND APPARATUS FOR FRICTION WELDING

(71) We, JOHN THOMPSON (PIPEWORK AND ORDNANCE DIVISION) LIMITED, a British Company, of Ettingshall, Wolverhampton, in the County of Stafford, do hereby declare the invention for which we pray that a Patent may be granted to us and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to a method of and apparatus for effecting friction welding of workpieces to establish a welded junction between them.

Hitherto friction welding has generally been effected between workpieces by holding the workpieces with respective faces thereof situated at the site at which the welded junction is required to be formed in contact with each other over said faces and subjecting the workpieces to relative rotation about an axis at right-angles to the faces, continuing the rotation until the material of the workpieces adjacent to said faces has been raised to a temperature at which it is possible to establish a fused union and then stopping the relative rotation while continuing to exert relative axial pressure between the contacting faces to cause the union to take place.

In relation to this method as hitherto generally practiced one serious objection is that portions of the faces furthest removed from the axis of rotation, are subjected to a much higher relative rubbing velocity with respect to each other, than are portions of the faces situated nearer to the axis of rotation, and indeed in coincidence with the axis there is no relative rubbing between the faces. Consequently it is difficult to ensure that each element of the material adjacent to the faces of the workpieces reaches a proper temperature to enable effective fused union to be established between the workpieces over the entire areas of the faces.

The problem of ensuring that each element of the material adjacent to the faces of the workpieces to be joined reaches such a proper temperature is even greater in cases where it is desired to join workpieces, one or both of which presents a non-circular face at a site at which it is desired to form a welded junction by the method mentioned above.

Another problem which is encountered is that since an effective fused union can take place only if relative rotation between the workpieces is discontinued, and the interval of time elapsing between attainment so far as possible of a proper temperature in layers of material adjacent to the faces to effect fused union between them, and cessation of relative rotation, should be kept to a minimum, it has hitherto been necessary to provide powerful brake means to ensure that relative rotation is discontinued in the required short interval of time.

Not only does such brake means require to dissipate a large quantity of energy when ever it is brought into operation, but there is obviously a great wastage of power in operation of the apparatus since the rotating parts must repeatedly be brought up to a proper speed of relative rotation and then subjected to braking.

One object of the present invention is to provide a new or improved method of friction welding and an apparatus for carrying out such a method whereby one or more of the above mentioned disadvantages are eliminated or reduced.

A further requirement which militates against the joining together by the method described above of two workpieces of non-circular cross-section is that it is normally necessary to form the junction between such workpieces whilst the latter are held in a predetermined proper orientation relative to each other. This cannot conveniently be effected if the method previously described is used to form a welded junction.

A further object of the invention is to provide a new or improved method of friction welding by means of which workpieces, at least one of which has a non-circular cross-section, can be united with each other.

According to one aspect of the invention

there is provided a method of friction welding workpieces formed of the same or different metals capable of being united to each other by friction welding wherein the workpieces are brought into contact with each other over respective faces thereof situated in the plane of the welded junction to be formed between them, and are subjected to a first mode of relative orbital movement in said plane to rub said faces together and are simultaneously urged towards each other to maintain contact pressure between the workpieces, and are also subjected to a second mode of relative movement in said plane generally transverse to said first mode in a sense to bring the workpieces into the relative position in which they are required to be welded together and to discontinue the relative movement when the temperature of layers of the material in the workpieces respectively adjacent to said faces reaches a value at which a fused union can be formed between them under continued pressure between the workpieces.

Said first mode of relative orbital movement may be relative movement along a circular path around the relative position in which the workpieces are to be welded together, the recond mode of movement being relative movement radially inwardly of said path towards said relative position.

It will be understood however that the first mode of relative orbital movement may be other than along a circular path. For example, such relative orbital movement may be performed along an elliptical path, or along some other path in the form of a lissajous figure.

A further feature of the invention is that said second mode of relative movement may be effected by reducing to zero the accentricity of an element of a transmission means serving to transmit the relative orbital translatory movement to the workpieces from a rotary driving member. Utilization of this feature of the method avoids the necessity for applying braking means to the rotary driving member and thus eliminates, or very substantially reduces the loss of power which has been inherent in methods of friction welding heretofore practiced.

The first and second modes of relative movement between the workpieces may be effected whilst each of the workpieces is maintained in an unvarying angular position relative to a reference axis. Alternatively, some component of rotational or oscillatory movement about said reference axis, may be applied to one or both workpieces in combination with the translatory movement.

The first mode of relative orbital movement may be selected so far as possible, as to ensure in each complete cycle of such orbital movement, that each elemental area of each of the two faces of the workpieces respectively in contact with each other, is subjected to rubbing contact with the other face for the same period of time. For workpieces of the same cross-sectional shape and dimensions there will intrinsically be an outer zone of the face of each workpiece, of a width dependent upon the eccentricity of the relative orbital movement, over which zone there is a shorter overall period of rubbing contact than is the case for positions of the faces situated inwardly of such zone. However, by keeping the eccentricity to a low value relatively to the cross-sectional dimensions, or average value thereof, any inequality in heating over the areas of the faces can be likewise reduced. If desired, an additional component of movement either rotational or oscillatory can be selected to compensate for this difference in heating and still further improve uniformity of heating.

It will further be understood that whilst conveniently in some cases one of the workpieces may be held stationary and the entire relative orbital movement applied to the other of the workpieces, it may be convenient in other cases for different components of the orbital movement to be applied to the workpieces respectively. Thus the first mode of relative movement of the workpieces which is a relative orbital movement may be achieved by imparting to the workpieces respective absolute movements, neither of which is orbital. For example, where the relative orbital movement is along a circular path about a reference axis, one workpiece may be reciprocated in accordance with a simple harmonic equation of motion along a rectilinear path at right angles to said reference axis and the other workpiece may be reciprocated in accordance with a like equation of simple harmonic motion along a rectilinear path at right angles to both the reference axis and the first said path, in such phase to the first component of reciprocation as to produce relative circular translatory movement about the reference axis. It is contemplated that the relative phases of these two components of motion and the relative magnitudes of these two components could be varied as desired to produce any selected mode of orbital motion composed of reciprocations which individually are performed in accordance with a simple harmonic law.

Yet another feature of the invention is that each one of a set of workpieces (two or more in number) may be friction welded to a respective one of another set of workpieces (corresponding in number to the first said set) by supporting all the workpieces of the first set in a first holder and all the workpieces of the second set in a second holder, between which holders said relative movement is applied.

Also according to the invention we provide an apparatus for carrying out the method of friction welding in accordance therewith, such apparatus comprising a supporting structure, holders thereon for supporting respec-

tive workpieces in positions with plane faces of these workpieces in contact with each other, means for maintaining contact pressure between said faces, drive means for moving the holders relatively to each other in a first mode of relative orbital movement involving movement of one holder relatively to the other around a relative datum position, and means for varying the relative motion of the holders to bring the holders into said relative datum position.

The drive means may comprise a rotary driving member, an eccentric element for converting rotary motion into translatory motion, and the means for varying the relative motion may comprise an adjustment means for varying the effective eccentricity of the eccentric element from a predetermined value down to zero whilst the rotary driving element continues to rotate.

The invention will now be described, by way of example, with reference to the accompanying drawings wherein:—

FIGURE 1 is a diagrammatic view illustrating the performance of the invention to effect friction welding between two workpieces of rod or bar-like form in circular cross-section;

FIGURE 2 shows the workpieces in side elevation during the initial stages of performance of the method and during the final stage;

FIGURE 3 is a diagrammatic view showing a first form of apparatus wherein the whole of the relative translatory orbital movement is applied to one of the workpieces whilst the other is stationary;

FIGURE 4 is a diagrammatic view of a second form of apparatus for performing the method wherein respective components of translatory orbital movement are applied to respective workpieces,

FIGURE 5 is a fragmentary diagrammatic view showing a modification of the form of an apparatus illustrated in Figure 4,

FIGURE 6 is a fragmentary diagrammatic view in end elevation and in cross section of a third form of apparatus for performing the method wherein respective components of relative translatory movement along a path in the form of a lissajous curve are applied to respective workpieces only the holder and a portion of the drive means for one of the workpieces being shown, and

FIGURE 7 is a fragmentary view showing in isolation the eccentric element of the apparatus of Figure 6.

In the manner of carrying out the method of the invention illustrated diagrammatically in Figures 1 and 2, the workpieces 10 and 11 to be joined by friction welding are shown as rods of circular form in cross section and of equal diameter. Of course these rods may be formed of any metal or different metals capable of being united to each other by friction welding.

For clarity in Figures 1 and 2 one of the workpieces, namely 11, is shown in broken lines.

The workpiece 10 is supported stationarily in any suitable form of holder, and translatory movement in a first mode, namely along an orbital path is applied to the workpiece 11. Figure 1 shows four relative positions of the two workpieces at positions spaced apart at equal intervals along a circular path having a radius represented by the dimension e.

It will be noted that reference diameters $10a$ and $11a$ drawn on the workpieces remain vertical and indicate that both workpieces maintain constant angular position relative to the reference axis 12 (being the axis of the workpiece 10) about which the orbital movement takes place.

Any suitable means is provided to maintain end faces of planar form $10b$ and $11b$ in pressure contact with each other during orbital movement of the workpiece 11 about the reference axis. For example, the contact pressure may be applied by a pressure fluid energised piston and cylinder unit urging one of the two holders towards the other in a direction longitudinally of the reference axis 12.

The orbital movement is continued until the temperature of layers of material in the workpieces respectively adjacent to the end faces $10b$ and $11b$ reaches a value at which the fused union between the surface layers of metal is capable of being effected.

In practice, the attainment of this stage can usually be determined by carrying out the orbital movement for a predetermined period of time but other parameters dependent upon the temperature of these layers of material may be utilised if desired. For example, when the temperature of the surface layers of the material approaches that at which the fused union can take place, material in these layers becomes softened and relative axial movement of the workpieces towards each other under the influence of the forces applied by the pressure applying means may take place causing some slight upset of these layers of material adjacent to the faces $10b$ and $11b$ in contact. This relative axial movement may be detected and its incidence utilised to bring about cessation of the orbital movement.

Ordinarily it is convenient to apply the orbital movement by a unidirectionally rotating driving member driving an eccentric element such as a crank or a cam. To bring about cessation of the orbital movement without necessarily stopping the rotary driving member relative movement in a second mode generally transverse to that of the first mode is applied to the workpieces such that the eccentricity e is reduced to zero, and thence relative orbital movement in the first mode is no longer transmitted to the workpieces from

the driving member. The workpieces 10 and 11 are thus brought into the relationship illustrated in *b* of Figure 2 and the axial pressure continues to be applied to the two workpieces in a direction towards each other to cause the softened surface layers of material adjacent to the faces 10*b* and 11*b* to become fused together. This operation will further increase the degree of upset at the junction between the workpieces. Such upset is omitted from the drawings. In many classes of work the existence of the upset can be tolerated but in other cases surplus material can be removed by a grinding or other abrading operation.

It is contemplated that the magnitude of the eccentricity *e* may be varied as required for different sizes, cross-sectional shapes and materials of which the workpieces are composed. In general a value of eccentricity which is small compared with the diameter or equivalent cross-sectional dimension of the workpiece, may successfully be used in many cases. For example, in welding together mild steel pieces of rod stock having a diameter of upwards of half an inch, it is contemplated that an eccentricity of about a 1/16 of an inch will produce satisfactory results using values of contact pressure corresponding to those employed in conventional friction welding processes wherein the workpieces are subjected to simple rotation about the reference axis.

The speed of orbital movement may also be varied widely to produce a satisfactory welded junction between the workpieces of different sizes, cross-sectional shapes and materials. It is contemplated that orbital movement performed at the rate of from 2,000 to 12,000 cycles per minute will enable most classes of work to be successfully handled.

Although in the method illustrated diagrammatically in Figures 1 and 2, neither of the workpieces is subjected to any angular displacement about its own axis during the performance of the relative orbital movement, such angular displacement could be utilized in combination with the translatory orbital movement. It will be evident from Figure 1 that surface portions of each end face 10*b* and 11*b* which lie inwardly of a radius equal to the radius of the workpiece, less the eccentricity *e* are continuously in contact with each other, whereas surface portions of the end faces which lie outside this radius are in contact with the companion end face, for part only of the cycle.

Since the relative translatory speed at which rubbing between the end faces takes place is constant over the entire area, more heat may be dissipated in the surface layers of material adjacent to the end faces inwardly of the radius mentioned in the preceding paragraph, than in the layers outwardly of such radius. The application of relative angular movement between the workpieces may be utilized to compensate for this inequality since such movement provides a relative rubbing speed which increases proportionally to the radius. Thus, conveniently translatory orbital movement could be applied to the workpiece 11 as shown, and oscillatory movement or rotational movement applied to the workpiece 10 about the axis 12.

Again it is to be noted that the method is not confined to the welding of workpieces of solid cross-section. One or both workpieces may be of hollow form for example tubular.

Where both workpieces are of hollow form, for example tubular, the value of eccentricity *e* would preferably not exceed half the value of the wall thickness of the workpiece having the lesser of the two wall thicknesses (if the wall thicknesses are unequal).

The invention is applicable with especial advantage to the welding together of workpieces of non-circular cross-section.

If these workpieces are of like shape and dimensions in cross-section for example square, rectangular, channel shape, or circular with a keyway or slot, it is important that when relative movement parallel to their contacting faces ceases, to permit welding to take place, the peripheral faces should be in accurately matching relation (i.e. the angular position of each workpiece about a reference axis should be identical). In carrying out the present invention the peripheral faces can be set accurately to matching relation when the workpieces are stationary at the beginning of the cycle, and thereafter they remain in this relative angular position although offset by the amount of the eccentricity during orbital movement. By simply reducing the eccentricity to zero without disturbance to the angular relationship the peripheral faces can again be brought into accurately matching relation without difficulty.

Furthermore, relative translatory movement, either alone or in combination with rotational or oscillatory (i.e. part-rotational) movement can produce heating of respective layers of the workpieces adjacent to the faces presented by the workpieces at the site of the welded junction which is to be formed, which is more even than heating which would be produced by rotational or oscillatory movement alone.

Figure 3 illustrates diagrammatically a simple form of apparatus which could be utilized for the performance of the method illustrated in Figure 1.

In this apparatus workpieces 10 and 11 are supported by holders 13 and 14 each incorporating a lower body portion 13*a*, 14*a* and an upper clamping portion 13*b*, 14*b*.

The body portion 13*a* of the holder 13 is connected to a pressure applying means such as a piston and cylinder unit 15 energized penumatically or by hydraulic fluid to urge

the end face of the workpiece 10 into contact with the adjacent end face of the workpiece 11. The holder 13 may alternatively be of conventional construction and adapted to rtate the workpiece 10 about its own axis.

The body 14*a* of the holder 14 is driven with a translatory orbital motion from a motor 16 through a transmission means 17 for converting the rotary motion of the output shaft 18 of the motor into the required translatory orbital motion. One form of mechanism which may be employed for this purpose comprises a pair of parallel rotary driving shafts 19 and 20 driven from a gear 21 meshing with gears 22 and 23 on the shafts respectively. The shafts carry respective eccentric elements in the form of crank discs 24 and 25 provided with respective crank pins 26 and 27 which preferably are adjustable to vary the eccentricity or throw in each case. For this purpose the crank discs may have slots 24*a* and 25*a* along which mounting blocks 26*a* and 27*a* for the two crank pins respectively are moveable through a range of movement providing zero eccentricity and any predetermined value required.

There may also be provided an adjustment mechanism to adjust the blocks 26*a* and 27*a* while the shafts and the crank discs 24 and 25 are in motion.

The crank pins 26 and 27 are engaged rotatably with a downwardly extending bar 28 fixed to the body 14*a* of the holder 14.

An alternative form of apparatus is illustrated in Figure 4.

In this case, the apparatus is designed to carry out a method of the invention by applying separate components of translatory orbital motion to the workpieces respectively.

Parts corresponding to those already described are designated by like numerals of reference with the prefix 1 and the preceding description is to be deemed to apply.

Thus as shown, workpieces 110 and 111 are supported by holders 113 and 114 each including a body part 113*a*, 114*a* respectively and a clamping part 113*b*, 114*b* respectively.

The holder 113 is movable horizontally and for this purpose is supported by means of a pair of leaf or blade springs 130 clamped by means of fastening elements such as bolts to an attachment portion of the body part 113*a* in the form of a block or spigot 113*c*. The lower ends of the springs 130 are similarly clamped or secured by bolts to a block or spigot 131 on a fixed part of the frame structure of the apparatus.

This supporting arrangement constrains the holder 113 to substantially horizontal reciprocating movement in the direction indicated by the arrow 134 without involving any relative sliding or rotation between the holder and its support or between the support and the frame of the apparatus.

The holder 114 is supported in a similar manner except that instead of the springs 132 extending in spaced, parallel vertical relationship, they are arranged in spaced parallel horizontal relationship and are clamped by means of fastening elements to blocks or spigots 114*c* on the holder 114 and 133 on a member of the frame. The holder 114 is thus constrained to reciprocating movement in a substantially vertical direction as indicated by the arrow 135.

The dimensions of the leaf or blade springs 130 and 132 are such as to provide rigidity in relation to forces exerted along the axis 112. One of the two holders 113 and 114 is so mounted as to be movable in a direction along the axis, for example such movement may be applied by a piston and cylinder unit 115 to the frame member from which the holder 114 is supported through the intermediary of the springs 132.

Components of simple harmonic reciprocating motion are applied to the holders 113 and 114 from a rotary drive motor 116 through the intermediary of two transmission means 136*a* and 136*b*.

Since apart from a difference in the attitude or angular position of the component parts of these two transmission means they may be identical, only one will be described.

Parts in the other transmission means are designated by like numerals of reference with the suffix *b*.

Transmission means 136*a* comprises a lever 138*a* pivoted about a horizontal axis 139*a* midway between its ends, and affording a guideway in the form of a slot 140*a*. A slide block 141*a* is movable along the slot and is pivotally connected to one end of a rigid link 142*a*, the other end of which is pivotally connected between the limbs of a slotted attachment lug 113*d* on the holder 113. The lever 138*a* and the part of the frame structure (not shown) on which it is pivoted may be constructed to ensure that the axis 139*a* is situated medially of the slot 140*a*, so that the pivotal axis of the connection between the slide block 141*a* and the link 142*a* can be brought accurately into coincidence with the axis 139*a* in one position of the block. This corresponds to a position of zero eccentricity for the transmission means. The frame structure may thus comprise a stirrup-shaped bracket mounted behind the slotted lever 138*a*, as seen in the drawing, and providing a sufficient clearance space therefrom to permit unobstructed movement of the slide block along the slot.

The lever 138*a* is arranged to extend generally upwardly and downwardly. At its lower end the lever 138*a* is connected by means of a link 145*a* to an eccentric element in the form of a variable throw crank 144*a*. The latter may comprise a crank disc formed with a radial slot in which is secured a crank pin

which can be secured in any desired position therealong.

The crank 144*a* is driven through gears 146*a* and 147*a*, the latter being disposed on the drive shaft 148 of the motor 116 and keyed or otherwise fixed thereto.

In the transmission means 136*b* the lever 138*b* is arranged generally horizontally instead of generally vertically.

Consequently, whilst the reciprocating motion imparted to the holder 113 by the transmission means 136*a* is horizontal in conformity with the arrow 134, the motion imparted by the transmission means 136*b* to the holder 114 is vertical in conformity with the arrow 135. In both transmission means, an adjustment means (not shown) is provided in association with the levers 138*a* and 138*b* to enable the slide blocks 141*a*, 141*b* respectively to be adjusted along the slots 140*a*, 140*b* respectively to any desired position. When the slide blocks are moved into alignment with the pivotal axes 139*a*, 139*b* the effective eccentricity of the two cranks is zero and no motion is transmitted to the holders 114 and 113 by the transmission means 136*a* and 136*b*. Each block can be moved in either direction from this position steplessly to any position along the associated slot to provide transmission of drive to the holders and to vary the relative motion of the holders.

Relative translational movement of the workpieces 110 and 111 along an orbital path can be brought about by driving both of the transmission means 136*a* and 136*b*. In this case, both of the workpieces will be reciprocated along repective rectilinear paths with simple harmonic motion. The motion of one workpiece relative to the other may be circular or elliptical and in either the clockwise sense or anti-clockwise sense, according to the phase relationship between the two components of rectilinear simple harmonic motion. Means may be provided for adjusting this phase relationship. For example, the cranks 144*a* and 144*b* may each include more than one radial slot, these slots being situated at positions spaced apart angularly about the axis of the crank, and the crank pin concerned may be mounted in any selected one of the slots. Alternatively, the gear pairs 146*a*, 147*a* and/or 146*b*, 147*b* may be so arranged that they can be moved out of mesh and then re-engaged in a different angular relationship.

This relative orbital movement of the workpieces constitutes the first mode of relative movement hereinbefore referred to. The second mode of relative movement, which is relative movement towards the relative position in which the workpieces are to be welded together, that is towards the centre of the orbital path, is brought about by reducing the amplitude of the simple harmonic reciprocating motion of the workpieces. The workpieces reach the relative position in which they are required to be welded together when the amplitude of the absolute motion of each workpiece reaches zero.

Any suitable means may be provided in the transmission means 136*b* to accommodate the axial movement imparted to the holder 114 from the piston and cylinder unit 115. For example, the connection between the link 142*b* and either the attachment lug 114*d* or the lever 138*b* may accommodate such axial movement. For example, in the latter case, the dimension of the slide block 141*b* in the direction of the axis 112 may be such that the block is slidable through the slot 140*b* in the direction of the axis 112 without loss of the connection between the lever 138*b* and the link 142*b*.

Instead of supporting the holders 113 and 114 by leaf or blade springs mounted as cantilevers, such leaf or blade springs may be supported from a suitable frame or body member at both ends so as to contitute beams and the holders would then be mounted at a position midway between the supported ends of the blade or leaf springs. Such an arrangement would still further increase the rigidity of the support arrangements relative to the forces applied along the axis 112.

Yet another alternative is illustrated in Figure 5 in respect of one only of the holders, although it will b eunderstood that each may be supported in a like manner, one for vertical and the other for horizontal reciprocatory movement. In this arrangement parts already mentioned are designated by like numerals of reference with the prefix 2 and th preceding description is to be deemed to apply. In this case the body portion 213*a* of the holder is formed with a slide section 213*c* of dove-tail section engaging in a correspondingly shaped slideway 250 formed in a guide member 251.

If desired, the slide section 213*e* and the slideway 250 may be dimensioned to provide a gap between their corresponding faces to enable fluid under pressure to be supplied to the gap from any suitable source thereof, thereby providing hydro-static suspension for the holder 213. The slideway 250 and slide section 213*e* are so arranged that the base of the slideway lies in a plane perpendicular to the axis of the workpiece. With this arrangement the major thrust exerted axially of the workpiece, and occurring during operation of the apparatus, is borne by the layer of fluid between the base of the slideway and the opposing face of the slide section, and effectively eliminates or minimises frictional forces which would otherwise be brought into being as a result of this load.

Referring now to figures 6 and 7, there is shown a workpiece holder and transmission means therefore which is also arranged to

reciprocate a workpiece with simple harmonic motion.

The workpiece 51 shown in Figure 6 is of rectangular cross-section and is supported in a holder comprising a body portion 52 and a clamping portion 53 of a shape suitable to clamp the rectangular workpiece between them. However, the holders shown may be substituted by any holder of a form suitable to support a different workpiece.

The body portion 52 of the holder is secured to or, preferably, formed integrally with a slide block 54, slidably mounted for rectilinear motion in a slideway provided in a supporting frame 55. The slideway may be provided with a hydrostatic bearing as described with reference to Figure 5 to minimise friction between the slide block and the slideway and is preferably so formed as positively to prevent their relative movement in all but one direction.

The slide block 54 is formed centrally on each end face presented in the direction of the permitted sliding motion with a blind cylindrical bore 56 which forms a part of an hydraulic piston and cylinder assembly for transmitting movement from a rotary driving member to the workpiece holder.

The supporting frame 55 is further provided with a pair of hollow cylindrical spigots 57, each of which co-operates with a respective one of the bores 56. The spigots are a sliding and substantially fluid-tight fit within the respective bores 56 and may be provided with suitable sealing rings if required.

The piston and cylinder assembly further includes a pair of pistons 58 acting within respective bores 59 formed one in each of the spigots 57. Each bore 59 communicates directly with the respective bore 56 in the slide block 54 and these bores each contain hydraulic fluid. Inlet and outlet ducts 60, 61 for the hydraulic fluid in each piston and cylinder assembly communicate with portions of the bores 59 which are occupied by the pistons 58 at all positions of the latter except an extreme position reached at the end of a stroke. Thus the inlet and outlet ducts are closed with respect to the bores 59 during the major part of each stroke of the pistons.

The pistons are driven in a synchronised manner by respective eccentric elements 62, each of which includes an eccentric portion 63 presenting radially of its axis of rotation 64 a peripheral surface having the form of a simple harmonic motion cam, that is to say, each piston reciprocates with simple harmonic motion when driven continuously by its respective cam rotating at uniform speed. Each eccentric element further includes a cylindrical portion 65 co-axial with the axis 64. The cylindrical portion 65 is spaced axially from the eccentric portion 63 by an intermediate portion having a surface which merges smoothly with the surface of each of these portions.

It will be noted that the eccentric portions 63 of the two eccentric elements are of like form and a follower provided on one piston 58 contacts a point on the associated eccentric portion 63 which corresponds to a point diametrically opposed to that contacted by a follower of the other piston on its associated eccentric portion.

The eccentric elements 62 are each keyed to a respective shaft 66 on which they are axially slidable by means of an adjustment means (not shown). The shafts 66 are rotated continuously and uniformly by a rotary driving member (not shown).

When it is desired to reciprocate the workpiece 51 with simple harmonic motion, the adjustment means is actuated to move the eccentric elements 62 axially and in unison into positions in which cam followers provided on the pistons 58 engage the eccentric portions 63 of respective eccentric elements.

Alternatively the second workpiece may be mounted in a further holder as described with references to Figures 6 but slidable along a rectilinear path at right angles to the path of movement of the workpiece 51. In this case one or both the supporting frames is biased towards the other to establish contact pressure between the workpieces. By suitable adjustment of the relative phase of the motions of the workpieces, relative movement of the workpieces along a path having the form of any lissajous figure can be provided.

The piston and cylinder arrangement described with reference to Figure 6 provides for the force exerted on a piston 58 by an eccentric element 62 to be applied to the workpiece holder with a mechanical advantage equal to the ratio of the area of cross-section of the bore 56 to the area of cross-section of the piston 58.

Any leakage of hydraulic fluid from the bores 56 and 59 past the spigot 57 or the piston 58 is made up when the inlet and outlet ducts 60 and 61 are opened at the end of a stroke of the pistons. A feed means may be arranged to circulate fresh hydraulic fluid into piston and cylinder assembly at the end of each welding cycle, the withdrawn fluid being cooled preparatory to its recirculation to the piston and cylinder assembly.

It will be appreciated that the workpiece holders of each form of apparatus described herein could be substituted by holders for respective sets of workpieces, all the workpieces of a first set being concurrently welded to associated workpieces of a second set in the manner hereinbefore described relative to the welding together of only two workpieces at a time.

It will also be appreciated that the method according to the invention may conveniently

be used to join opposite ends of an intermediate workpiece concurrently to the ends of two terminal workpieces. The terminal workpieces may be stationarily supported with respective plain faces in pressure contact with plane faces at opposite ends of the intermediate workpiece, the latter being subjected to translatory movement by apparatus substantially as described with reference to Figure 3 or apparatus substantially as described with reference to Figure 6 until the desired temperature is reached.

In the performance of the method wherein components of reciprocating motion are applied respectively to the two holders for the workpieces, it will be understood that this reciprocating motion need not necessarily be in accordance with a simple harmonic characteristic. A linear characteristics providing approximately constant speed of travel in each direction with a short period of acceleration and deceleration at the extremities of the movement, may be utilised if desired.

It is also within the scope of the invention to friction weld each of a set of workpieces supported in a first holder simultaneously to a second, larger workpiece supported in a second holder by subjecting the set of smaller workpieces and the larger workpiece to relative translatory motion until welding temperature is reached, and thereafter discontinuing such motion whilst maintaining contact pressure between each of the smaller workpieces and the larger workpiece. Thus apparatus according to the invention may be provided with a first workpiece holder adapted to support a set of workpieces and with a second workpiece holder adapted to support a single, larger workpiece.

It will be apparent that eccentric elements having respective eccentric portions which have a form other than that of a simple harmonic cam may be substituted in the apparatus described with reference to Figure 6. However it is necessary that the displacement of the cam follower of a first piston outwardly of a pitch circle having a radius equal to the mean distance of this cam follower from the axis 66 should be equal at all times to the displacement of the cam follower of the second piston inwardly of a similar pitch circle having a radius equal to the mean distance of this cam follower from the axis 66 of the eccentric element.

It will further be appreciated that the apparatus of Figure 6 could be modified within the scope of the invention so that the two pistons are driven from a common eccentric element. Thus conveniently a single eccentric element of the form described with reference to Figure 7 may be arranged with its axis laterally off set from the path of movement of the workpiece holder and adjacent to the centre of the slide block. Each piston would be provided with an extension of generally U-shape when viewed axially of the eccentric element, the base of the U being parallel with an end face of the slide block. One arm of the U would be secured to its respective piston and the other arm would carry a cam follower to engage the eccentric element. The two cam followers would engage the eccentric element at diametrically opposed positions thereon.

Each piston and its respective U-shaped extension would constitute a rigid transmission member having no pivoted or otherwise relatively moveable parts, and would thus provide a reliable and positive transmission of movement from the eccentric element to the piston and cylinder assembly.

Certain of the matter disclosed herein is claimed in our copending application No. 29462/72 (Serial No. 1293532) divided from the present application.

WHAT WE CLAIM IS:—

1. A method of friction welding workpieces formed of the same or different metals capable of being united to each other by friction welding wherein the workpieces are brought into contact with each other over respective faces thereof situated in the plane of the welded junction to be formed between them, and are subjected to a first mode of relative orbital movement in said plane to rub said faces together and are simultaneously urged towards each other to maintain contact pressure between the workpieces, and are also subjected to a second mode of relative movement in said plane generally transverse to said first mode in a sense to bring the workpieces into the relative position in which they are required to be welded together and to discontinue the relative movement when the temperature of layers of the material in the workpieces respectively adjacent to said faces reaches a value at which a fused union can be formed between them under continued pressure between the workpieces.

2. A method according to claim 1 wherein said first mode of relative movement is relative movement in a circular path extending about the relative position in which the workpieces are required to be welded together.

3. A method according to claim 1 or claim 2 wherein the second mode of relative movement is brought about by reducing to zero the eccentricity of a transmission means serving to transmit the relative movement to the workpieces from a rotary driving member.

4. A method according to any preceding claim wherein the workpieces are subjected to a third mode of relative movement concurrently with said first mode, such third mode being a rotational or oscillatory movement about a reference axis extending perpendicularly of said faces of the workpieces which are in contact with each other.

5. A method according to any preceding claim wherein one of the workpieces remains stationary whilst said relative movement is imparted entirely to the other of said workpieces.

6. A method according to any of claims 1 to 4 wherein a first of said workpieces is subjected to a first component of said relative orbital movement and a second of said workpieces is subjected to a second component of said relative orbital movement.

7. A method according to claim 6 wherein said first workpiece is reciprocated along a first rectilinear, or approximately rectilinear, path parallel to said plane, and said second workpiece is reciprocated along a second rectilinear, or approximately rectilinear, path which is at right angles to said first path and also parallel to said plane.

8. A method according to claim 7 wherein said first workpiece and said second workpiece undergo simple harmonic motion along their respective paths.

9. A method according to any one of the preceding claims wherein one or both of the workpieces is or are of non-circular shape in a cross-sectional plane parallel to said faces of the workpieces.

10. A method according to any preceding claim wherein each one of a first set of workpieces is friction welded to a respective one of a second set of workpieces (the two sets having equal numbers of workpieces) by supporting all workpieces of the first set in a first holder and all workpieces of the second set in a second holder, between which holders said relative movement is applied.

11. Apparatus for friction welding comprising a supporting structure, holders thereon for supporting respective workpieces in positions with plane faces of these workpieces in contact with each other, means for maintaining contact pressure between said faces, drive means for moving the holders relatively to each other in a first mode of relative orbital movement involving movement of one holder relatively to the other around a relative datum position, and means for varying the relative motion of the holders to bring the holders into said relative datum position.

12. Apparatus according to claim 11 wherein said drive means includes a driving member and transmission means for transmitting drive from said driving member to the or one of the holders, the transmission means being adjustable by said means for varying the relative motion in such a manner as to bring the holders towards and into said relative datum position without arresting the driving member.

13. Apparatus according to claim 11 wherein the driving member is rotatable, and the transmission means includes an eccentric element for converting rotary motion into translatory motion, said means for varying the relative motion being arranged to vary the effective eccentricity of the eccentric element from a predetermined value down to zero whilst the rotary driving member continues to rotate.

14. Apparatus according to claim 13 wherein said eccentric element is rotatable about an axis by said driving member, and is movable axially of said axis by said means for varying the relative motion, and includes an eccentric portion having the form of a cam in cross-section transverse to said axis of rotation, and a cylindrical portion coaxial with said axis of rotation and spaced axially thereof from said eccentric portion.

15. Apparatus according to claim 14 wherein each of said workpiece holders is provided with one of the piston and cylinder of a respective piston and cylinder assembly, the other of the piston and cylinder being movable by said eccentric element to transmit translatory movement to the holder through the intermediary of fluid contained within the piston and cylinder assembly.

16. Apparatus according to any one of claims 11 to 16 further including means for imparting to said workpiece holders relative rotational or oscillatory movement about a reference axis extending perpendicularly of said faces of the workpieces which are maintained in contact with each other.

17. Apparatus according to any of claims 11 to 14 wherein one of the workpiece holders is stationarily mounted on the supporting structure.

18. Apparatus according to any of claims 11 to 16 wherein said drive means is arranged for imparting to a first of said workpiece holders a first component of said relative translatory movement, and a second component of said movement to a second of said workpiece holders.

19. Apparatus according to claim 18 wherein said first workpiece holder is arranged for reciprocation along a first rectilinear, or approximately rectilinear, path and said second workpiece is arranged for reciprocation along a second rectilinear, or approximately rectilinear, path which is at right angles to said first path.

20. Apparatus according to claim 11 wherein said drive means is arranged to reciprocate at least one of said workpiece holders with simple harmonic motion.

21. Apparatus according to any of claims 11 to 20 wherein the workpiece holders are adapted to support respective sets of individual workpieces, each set comprising at least two workpieces, with a plane face of each workpiece of one set in pressure contact with a plane face of an associated workpiece of the other set at the site of a welded junction to be formed between such associated workpieces.

22. A method according to claim 1 of

friction welding workpieces formed of the same or different metals capable of being united to each other by friction welding substantially as hereinbefore described with reference to the accompanying drawings.

23. Apparatus according to claim 11 substantially as hereinbefore described with reference to and as shown in Figure 3 of the accompanying drawings.

24. Apparatus according to claim 11 substantially as hereinbefore described with reference to and as shown in Figure 4 of the accompanying drawings.

25. Apparatus according to claim 24 but modified substantially as shown in Figure 5 of the accompanying drawings.

26. Apparatus according to claim 11 substantially as hereinbefore described with reference to and as shown in Figures 6 and 7 of the accompanying drawings.

FORRESTER, KETLEY & CO.,
Chartered Patent Agents,
Rutland House, 148 Edmund Street,
Birmingham B3 2LD,
and
Jessel Chambers, 88/90 Chancery Lane,
London WC2A 1HB.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1972.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1293531 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

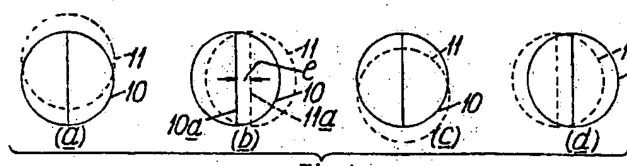

Fig. 1.

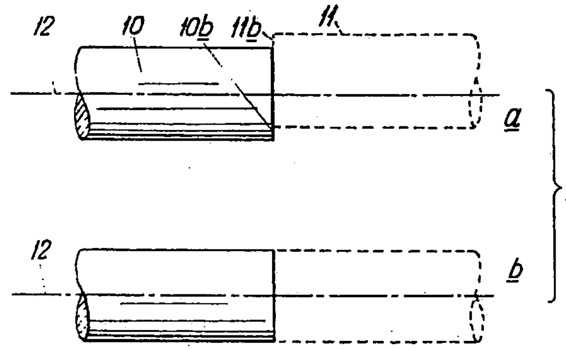

Fig. 2.

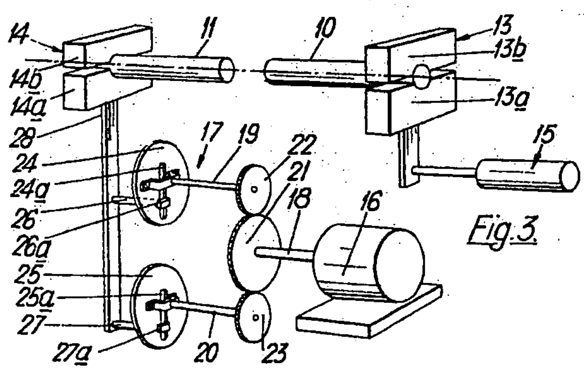

Fig. 3.

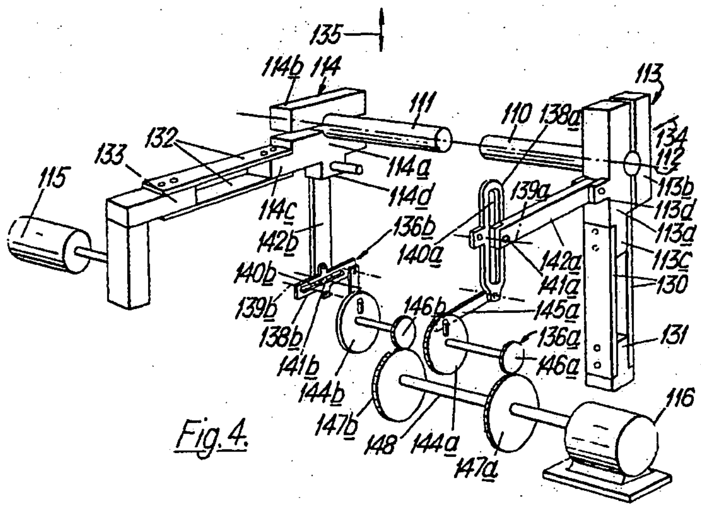
135
114b
114
111
110
138a
113
134
112
113b
113d
113a
113c
130
131
132
133
115
114a
114d
114c
142b
136b
139a
140a
142a
141a
145a
140b
139b
138b
141b
144b
146b
136a
146a
147b
148
144a
147a
116

Fig.4.

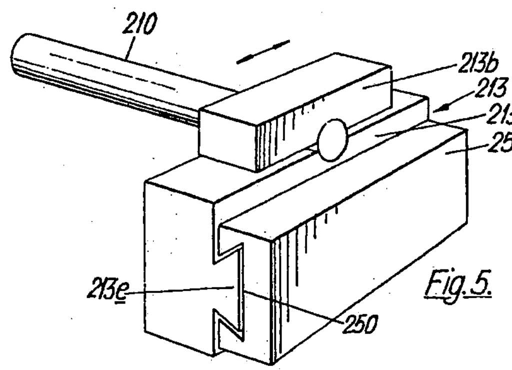
210
213b
213
213a
251
213e
250

Fig.5.

1293531 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

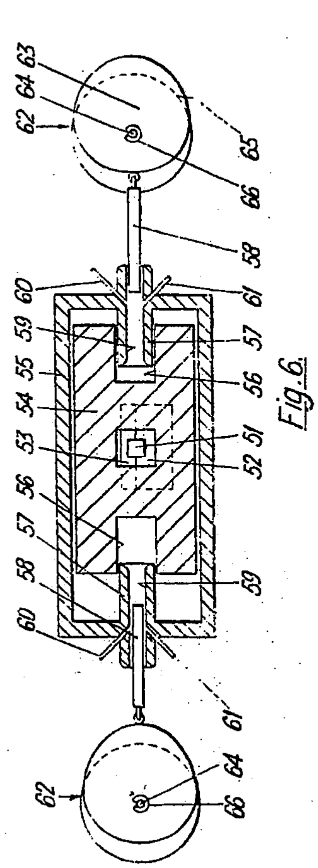

Fig.6.

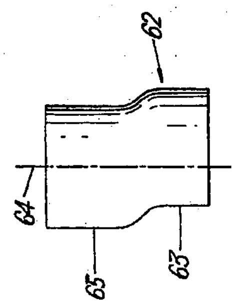

Fig.7.